Cavity-Enhanced on-demand Spin-Wave Solid State Quantum Memory

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The realization of large scale quantum networks requires the distribution of entanglement over large distances. In this long-range regime, direct transmission is prohibitive due to losses in optical fibers. Quantum repeaters are predicted to overcome direct transmission and allow entanglement distribution at a continental scale. Most quantum repeater schemes rely on the storage of quantum states into quantum memories. In order for memories to be useful in practical implementations, they must exhibit several features including long storage time, a high storage efficiency and a large multiplexing capability. Solid-state quantum memories based on rare-earth doped solids promise excellent performances in terms of storage time and multiplexing capability [1].

The efficiency of quantum memory protocols decays exponentially with storage time due to the limited coherence time of the material. This severely limits the applicability of the quantum memory. Storage in a spin-state has the advantage, that spin-rephasing techniques can be applied to mitigate the decay of the efficiency with longer storage time.

The efficiency for spin-wave storage at the single photon level in a crystal was so far limited to around 31% using the spectral-hole memory protocol [2] which does not allow temporal multiplexing. The highest efficiency using spin-wave-storage with the atomic frequency comb protocol (AFC), which features intrinsic temporal multiplexing capability, was reported by Jobez et al [3] with 12% for bright classical pulses.

To compensate for the limited optical depth available in rare-earth doped crystals, it was suggested to place a weakly absorbing sample in an impedance matched optical cavity [4]. So far, this technique was demonstrated at quantum level only for storage in excited state, without on-demand read-out. Here we report the first demonstration of a cavity enhanced spin-wave quantum memory with on-demand read-out. Using the AFC in a Pr doped crystal, we reached a device efficiency over 38% for storage in the spin-state. Maintaining a good signal-to-noise ratio is more challenging for storage in the spin-state than in the excited state. In our case, we reached a signal-to-noise ratio of about 18 with a mean input photon number of 0.9, making it feasible to store photons from a SPDC source. We further investigated the effect of the impedance-matched cavity on the noise level and characterized efficiency and signal-to-noise ratio as a function of the input photon's bandwidth and storage time (see Figure 1).

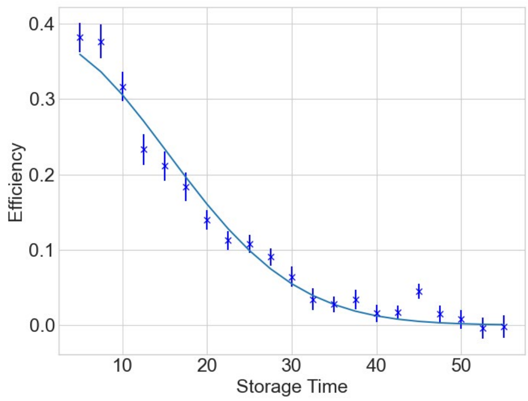

Figure 1: Scan of the device efficiency as a function of the on-demand storage time.

References

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